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Satellite Image Resolution Enhancement Using Dyadic-Integer Coefficients Based Bi-Orthogonal Wavelet Filters

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Abstract

The acquisition of high satellite Imagery becomes difficult due to the instrument limitation and imperfect imaging optics. Low spatial resolution satellite images consist a lot of mixed pixels which degrade the detection and recognition performance in civil and military applications. In this paper, a satellite image resolution enhancement using Dyadic-Integer coefficients based bi-orthogonal wavelet filters is proposed. Dyadic-integer-coefficient based wavelet filters are derived from the construction of a half-band polynomial. The splitting approach is used to develop the integer-coefficient based half-band polynomial. The possibility of these dyadic-integer coefficients based wavelet filters is explored in the field of image enhancement using sub-pixel image registration. The two-resolution frames are registered at a specific shift from one another to restore the resolution lost by the sensors. The discrete wavelet transform (DWT) obtained from the designed coefficients is applied on these two low-resolution images to obtain the high resolution image. The proposed method has been tested on satellite images. The quantitative (peak signal-to-noise ratio and root mean square error) and visual results show the superiority of the proposed technique over the conventional and state-of-art image resolution enhancement techniques.

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Keywords: Remote sensing, Multispectral, DWT, Resolution, Dyadic integer coefficient;

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1. Introduction

Now days satellite images are used in various applications such as surveillance, navigation, communication, remote sensing, and earth observation. Notable applications to remote sensing include those relating to meteorology, agriculture, mining, geology, mapping, city planning, ecological monitoring and disaster monitoring. Application of remote sensing increases with the development of sensors. Initially electro-optical visible sensors have been used, more recently, the application of thermal imagers, synthetic aperture radar (SAR), light detection and ranging (LIDAR) are used. Basically the remote sensing is classified into the Hyper spectral and the multispectral remote sensing [1].
One of the important issue of the remote sensing is the resolution of the image which plays the significant role in the real time land cover land use management. According to the domain the Image resolution enhancement techniques can be categorized into two major classes such as spatial domain and transform domain. In spatial domain the different techniques available such as gray level transformation, histogram modeling, gray level slicing, neighborhood pixel adjustments etc. The statistical and geometric data directly extracted from the input image itself [2], [3], while transform-domain techniques input image is transformed into the other transformations such as DFT,DCT or decimated discrete wavelet transform (DWT) to achieve the image resolution enhancement [4].

If an image has been taken in very dark or a very bright situation, the information may be lost in those areas which are excessively and uniformly dark or bright. Satellite images are low contrast and dark images, which has complete information but is not visible. The main issue is contrast improvement of input satellite images. We propose a new technique which generates sharper and detailed super resolved satellite images. The proposed technique uses Dyadic-Integer coefficients based bi-orthogonal wavelet filters for satellite image resolution enhancement.

2. Related work

The resolution of satellite images can be improved by various methods such as interpolation method, complex wavelet transform, wavelet padding zero and single frame resolution [6]. The main reason of the resolution enhancement can be attributed to the directional selectivity of the CWT, where the high frequency sub bands in six different directions contribute to the sharpness of the high frequency details such as edges. The Multirate filter banks and wavelets are widely used in the analysis, processing, and representation of digital signals [5] [6]. The specific class of filter banks with integer and rational coefficients is a better solution because of fast hardware-friendly finite-precision implementation and low power consumption. Generally, the design of wavelet FBs revolves around the orthogonal and bi-orthogonal wavelets. Both have their respective advantages. However, orthogonal wavelet are not symmetric that leads to non-linear phase. The linear phase plays an important role in order to handle boundary distortions of images [6- 7]. These both the characteristics (orthogonality and linear phase) exist in Haar wavelet. But, the Haar wavelet provides the discontinuous phase. Hence, the bi-orthogonal wavelet is preferred over orthogonal wavelets for image processing due to its linear phase characteristics. Most of the popular bi-orthogonal FBs (e.g. Cohen-Daubechies-Feauveau [11] (CDF) 9/7 and spline family of wavelet FBs) [8] are designed by the factorization of Lagrange half-band polynomial (LHBP), which has the maximum number of zeros at so as to achieve better regularity. However, LHBP filters do not have any degree of freedom and thus there is no direct control over frequency response of the filters. In order to have some independent parameters (which can be optimized to obtain some control over frequency response of the filter), Patil et al. [8] used general half-band filter factorization (not LHBP) to design two-channel bi-orthogonal wavelet FIR FBs (BWFB). However, factorization (decision of factorization of remainder polynomial and reassignment of zeros) improves the frequency response of one of the filters (analysis/synthesis) as compared to the other filter (synthesis/analysis). The improvement in the frequency response of both the filters totally depends on the factorization of a half band polynomial. This is somewhat tedious task for higher order polynomials. Rahulkar and Holambe [9] proposed a new class of triplet half-band filter bank (THFB) to solve these issues. However, the combined length of this FB is 32 which may not be suitable for hardware implementation. Also, the coefficients obtained from these above designed filter banks [8, 9] are irrational numbers that requires floating point arithmetic implementation. With this, the computational complexity increased due to which hardware implementation becomes difficult. Hence, it is need to design the filters which give hardware friendly dyadic coefficients. Naik and Holambe [10] have been achieved this objective by designing the family of low-complexity wavelet filters. Most of the researchers have been used the quantization criteria on the frequency response of the designed filters. However, the quantization affects on the performance of the designed filters [8] by the shift of the location of zero at $z = -1$. In this paper, a new specific class of dyadic-integer-coefficient based wavelet filter is designed and performance is compared with various orthogonal, Biorthogoanl and harr wavelet transforms.

3. Proposed method

The existing super-resolution schemes used the interpolation techniques [12]. However, the resulting image using this method contained blurred effect in the edges. Hence, multi-resolution analysis (MRA) based technique can be very useful in order to preserve the edges. It is well known that discrete wavelet transform (DWT) is a very powerful tool in MRA. The power of DWT is to give good time resolution for high frequencies and good frequency resolution for low frequencies. However, the presence of down-sampling by factor-2 in DWT causes the information loss in the respective sub-bands. Hence, in order to mitigate this effect, the three detail sub-bands without down-sampling factor (called as stationary wavelet transform) has been introduced in the interpolated detail sub-bands to obtain super-resolved image [11]. However, such type of wavelet based super-resolution algorithm introduced the spatial domain noise. This type of noise can be reduced with the help of wavelet-coefficient based thresholding technique. Thus, Chappalli and Bose [13] investigated the effect of soft-thresholding level on the reconstructed image quality by the use of existing wavelet based on the two-step lifting step. However, these algorithms required the irrational coefficients based wavelet filters that lead to increase the hardware computational complexity. The wavelet filter based on dyadic-integer coefficient is proposed to reduce the hardware complexity in the field of satellite image resolution. The detail algorithm is given in Fig.1

First, the two low-resolution images I_1 and I_2 are obtained from the original image based on the half-pixel shift in both the directions (row and column-wise). Both of these frames are then rotated by an angle of 45º using quincunx sampling so as to determine the measure of similarity of the pixel values between two frames. These rotated images are interpolated to denote the missing pixels in the super-resolution image. The proposed specific class of DICWFs is applied on these two rotated high-resolution images and the interpolation is performed at one scale. Next, the proposed class of reconstruction DICWFs are applied to these interpolated rotated images and combined into a single image. To obtain the super-resolved image, single image is the post-rotated back to its original orientation.

Original image is used to obtain the two low-resolution images (frames) I_1 and I_2 by quincunx sampling (sampling at half-pixel in horizontal and vertical directions of the original image) [14]. The image I_1 contains only the odd indices pixel values and the image I_2 contains even indices pixels. This shift in two images represents the diagonal motion of a camera; CCD array of the camera samples the area in this half-pixel manner. The quincunx sampled splits the pixel image of 6×6 into two 3×3 pixel images at desired half-pixel shift. The zeros indicate odd indices pixels and the cross indicates the even indices pixels. These two low-resolution frames are then combined on a quincunx sampling grid. These two low-resolution frames are placed into a high resolution frame correspond to half-pixel shift in x and y-directions [13]. By doing some transformation on these two-resolution frames, a high-resolution grid is obtained and can be written by Eq. (1) as:

$$H\,(x_H, y_H) = T\,((I_1(x_1, y_1), I_2(x_2, y_2)) \tag{1}$$

where, $H\,(x_H, y_H)$ is a quincunx sample of the desired high-resolution image, I_1 and I_2 are the two-resolution images (frames), and T is transformation to obtain quincunx sampling grid. The relationship between the co-ordinates of the two-resolution images and high-resolution is given by Eq. (2) as:

$$x_1 = 2x_H-1,\ y1 = 2y_H-1,\ \ x_2 = 2x_H,\ \ y_2 = 2y_H. \tag{2}$$

Next, the complete high-resolution image has been created by interpolating the missing pixels in the wavelet domainusing proposed class of separable DICWFs. In order to obtain the wavelet coefficients, the resultant sampling grid need to be rotated by angle of 45º so as to exploit the relationship between these two low-resolution images. This is achieved by using Eq. (3) as:

$$H_{rot}\,(x_{rot}, y_{rot}) = \mathrm{Rot}\,[H(x_H, y_H)] \tag{3}$$

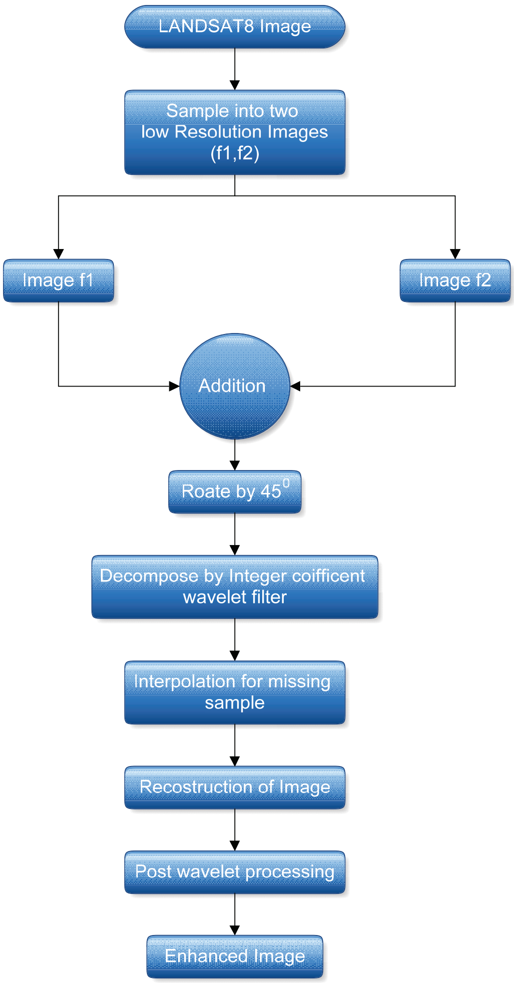

Fig. 1 Proposed algorithm

This rotated image is up-sampled by 2 in order to create the space for obtaining the missing pixel values. This resultant image is decomposed at the first level by the use of proposed class of DICWFs. With this, three detail sub-bands (LH, HL, and HH) and one approximation sub-band have been obtained. The missing pixel coefficients have been calculated using linear interpolation. The DICWFs are applied on this interpolated image to construct the high-resolution image by the use of post-wavelet domain processing.

4. Result and Discussion

The proposed method is validated by comparing the peak signal to noise ratio (PSNR) values of the proposed scheme with the PSNR values obtained from existing methods as given in table 1. The result of proposed method is given in the Fig.2. The performance of the proposed super-resolution scheme has been tested over four LANDSAT satellite images. The two low-resolved images have been obtained by half-pixel shift in x and y–directions from the original image. The PSNR values are known to be mathematically convenient, so generally used for judging image quality. The performance can be measured with the help of Mean Square Error also. The MSE and PSNR are inversely proportional. For calculation of these parameters original image and enhanced image is considered. The result shows that the PSNR of proposed method is comparatively more than the other methods.

Table 1 PSNR values for proposed DICWFs with other techniques.

	PSNR in dB			
	Malshiras, India	Flooding in Canada	Fire in California	Kolkata , India
Proposed DICWFs	52.94	56.23	59.42	63.52
Orthogonal wavelets(dB1)	52.31	55.93	59.04	63.24
Haar wavelet	52.31	55.93	59.04	63.93
Orthogonal wavelets(dB2)	23.79	25.71	25.10	25.10
Orthogonal wavelets(dB4)	23.27	25.23	24.60	24.58
Orthogonal wavelets(dB6)	23.048	25.033	24.39	24.37
Biorthogonal Bior3.1	22.92	24.82	24.16	24.17
Symlets sym3	23.52	24.45	24.82	24.82

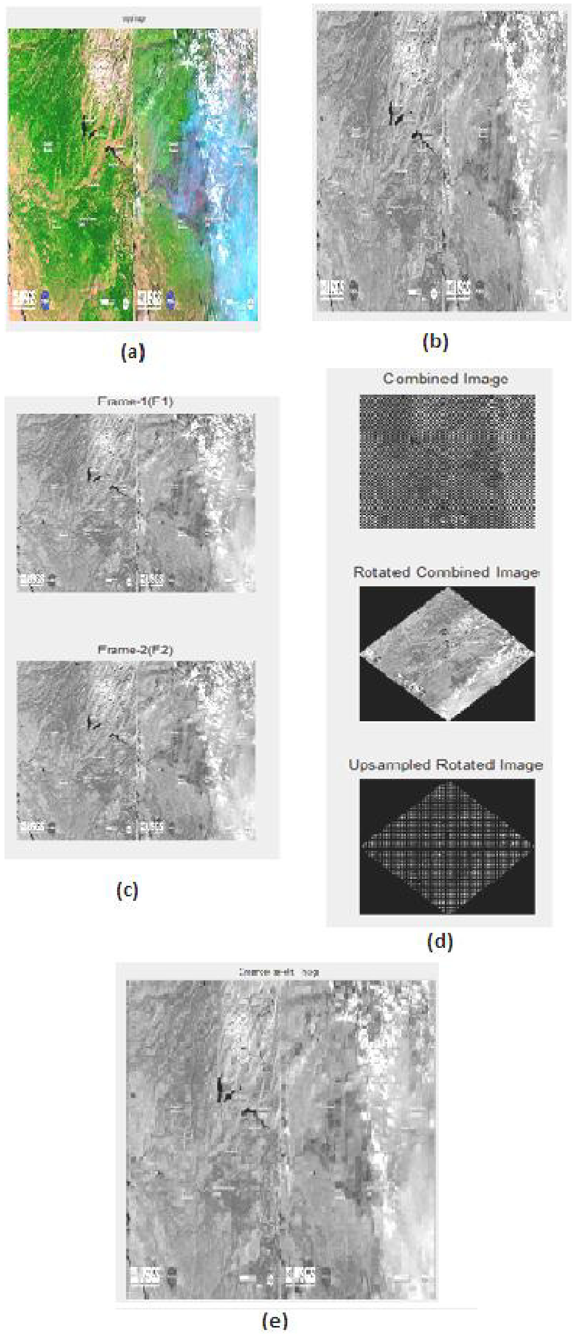

Fig. 2 Results; (a) original colour satellite image; (b) Gray scale satellite Image; (c) Generation two frames; (d) Combined, Rotated and Upsampled images; (e) Resolution enhanced satellite Image

5. Conclusion

The scheme of efficient satellite image enhancement is proposed by this implementation. The computational complexity of this method is less as compared to other well known techniques. The enhanced image has been reconstructed by registering the image frames at sub-pixel shift and interpolated the missing pixel locations in discrete wavelet domain. The two-resolution frames have been registered at a specific shift from one another to restore the resolution lost by CCD array of camera. The discrete wavelet transform (DWT) obtained from the designed coefficients is applied on these two low-resolution images to obtain the high resolution image. The proposed method improves the PSNR as compared to other methods.

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